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Evidence of intermittent fluctuations and multifractality of target residues in lepton-nucleus interactions at (420 ± 45) GeV

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Abstract : Analysis of target fragments of muon-nucleus interactions data at (420 ± 45) GeV in terms of Scaled Factorial Moments (SFMs) in one dimension azimuthal angle phase space is reported in our present paper. The SFMs are found to increase with decreasing bin width of the azimuthal phase space of the target fragments. The strength of the intermittency increases with the order of the moment. Thus this analysis reveals intermittent fluctuations as well as multifractality of target fragments

Keywords : Lepton–nucleus interactions, fluctuations, fractality

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1. Introduction

The power law behaviour of Scaled Factorial Moments commonly called intermittency phenomenon is used to extract non-statistical fluctuation after eliminating the statistical part [1]. The intermittency appears to be a general phenomenon in multi-particle production as well as target fragmentation process in high energy interactions. Initially many alternative suggestions, such as conventional short range correlations, formation of jets and mini jets, self-similar random cascading mechanism and B-E interference *etc.* are available but none of them can give satisfactory information. Thus, Scaled factorial moments have mostly been used as a diagnostic tool for extracting dynamical fluctuation of emission of particles in different types of high energy interactions. In high energy interaction, the emission of taget fragments are explained by evaporation model [2]. Due to interactions, three types of tracks are coming out from the target nucleus. At the instant of impact, the shower and grey tracks are emitted. The evaporated tracks emit at the later stage of the interactions *i.e.* from the residual nucleus. Emission of black tracks, takes place relatively slowly [3-5]. After the evaporation of first particle, the second particle is brought to the favourable condition for evaporation until the excitation energy of the residual nucleus becomes very small so that the transition to the ground state is likely to be affected by the emission of the γ-rays. This model is based on the assumption that statistical equilibrium has been established in the decaying system and that the life time of the system is much longer than the time taken to distribute the energy among the nucleons in the nucleus. By analyzing the experimental data of proton-emulsion experiments at the incident energies 67 GeV to 400 GeV, Takibaev *et al* [6], Adamovich *et al* [7] and Fuchs *et al* [8] observed the dominance of non-statistical fluctuation over the statistical part of angular distribution of black particles. In the recent study also, the angular distribution of black particles from muon-nucleus interactions could not be explained very satisfactorily by evaporation model. A few works have been reported for hadron-nucleus and nucleus-nucleus interactions [9-13]. However, no data is available for lepton-nucleus interactions at high energy. Recently, we studied the intermittency phenomena in terms of SFMs of black particles in muon-nucleus interactions at (420 ± 45) GeV [14, 15]. The study indicates intermittent emission in $\cos\theta$ space. This intermittent emission of target fragments prompted us to study whether similar intermittent type of fluctuation is present also in azimuthal angle space. The study of intermittency in azimuthal angle phase space is not only interesting but also essential to know the detail dynamics of target fragmentation process.

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2. Experimental details

The intermittency and target fragments study are performed with the help of emulsion technique because of the high spatial resolution with 4π geometry.

Exposure :

In this emulsion experiment, we have exposed stacks of G5 nuclear emulsion plates to the main muon beam at (420 ± 45) GeV in FERMI LAB (U.S.A.) [16]. The emulsions were allowed to warm to room temperature for 4 hours before the exposure. The two boxes were levelled to about ± 2 mrad. The beam intensity on the emulsion was monitored with a scintillator telescope with a circular aperture of 1.25 cm. (a counter with a 1.25 cm. diameter hole in anti coincidence with two counters 2.5 × 2.5 sq. cm). The density of the integrated exposure is 0.98 × 10^6 muouns / sq.cm. at the center, tapering off quadratically to 0.60 at 5 cm. from the centre (the edge of the emulsion sheets). The beam was deliberately defocused with quadrupoles to get a fairly even density on all parts of the emulsion.

Scanning and measurement :

The scanning of the events was done with the help of high resolution Leitz metalloplan microscope with an on-line computer system using objectives 10X in conjunction with a 10X ocular lens. The scanning is done by independent observers to increase the scanning efficiency which turns out to be 98%.

Criteria for selecting the events are :

(a) The events within 20 μm thickness from the top or bottom surface of the plates were not analysed.

(b) The beam track did not exceed 3° from the mean beam direction in the pellicle.

All the tracks are classified as usual :

(i) The target fragments with ionization > 1.4 I_0 (I_0 is the plateau ionization) produced either black or grey tracks. The black tracks with range < 3 mm. represent target evaporation (the light nuclei evaporated from the target) of β < 0.3, singly or multiply-charged particles.

(ii) The grey tracks with a range ≥ 3 mm. and having velocity $0.7 \geq \beta \geq 0.3$ are mainly images of target recoil protons of the energy range up to 400 MeV.

(iii) The relativistic shower tracks with ionization < 1.4 I_0 are mainly produced by pions and are not generally confined with the emulsion pellicle. The are believed to carry important information about the nuclear reaction dynamics. The azimuthal angle (ϕ) in the laboratory frame, of all the black tracks, is calculated by taking the space coordinates (x, y, z) of a point on the track, another point on the incident beam and the production point by using oil immersion objectives (100 X inconjunction with a 10 X ocular lens). The detailed characteristics for each event was obtained. The emulsion technique possess highest spatial resolution and thus most effective in studying correlation and enable us to study intermittency phenomena. Following the above selection procedure we have chosen 353 events in our sample plate of muon-nucleus interactions.

3. Method of analysis

Any fluctuation in the distribution of produced particles or target fragments, we speak about the term intermittency which can be defined in terms of SFMs. In azimuthal angle space (ϕ), for each event, we calculate SFMs as

$$F_q = \frac{1}{M}\sum_{j=1}^{M} M^q n_j(n_j-1)\ldots(n_j-q+1)/<n>^q, \quad (1)$$

where the full width of azimuthal angle space ($\Delta\phi$) is divided into M bins, each of size $\delta\phi = \Delta\phi/M$, n_j is the number of black tracks in the j-th bin, j running from 1 to M and $<n>$ is the average number of black tracks within the considered phase space region. q is a positive integer, which indicates the order of the moment. For given q and M values, F_q are calculated for all events and averaged over events to obtain $<F_q>$. For the non flat angular distribution, the correction factor R_q is given by

$$R_q = \frac{1}{M}\sum_{j=1}^{M} M^q \langle n_j\rangle^q / \langle n\rangle^q. \quad (2)$$

This formula is used to obtain the Corrected or Reduced Scaled Factorial Moments (RSFMs) which is given by

$$\langle F_{qR}\rangle = \frac{\langle F_q\rangle}{R_q} \quad (3)$$

This expression is more appropriate for the analysis of intermittency. Further, in case of flat distribution, R_q's are equal to unity.

It is to be mentioned that the intermittency exponents α_q is related with anomalous fractal dimension (d_q) as

$$\frac{\alpha}{q-1} = d_q, \quad (4)$$

where $d_q = 1 - D_q$ (5)

and D_q is called the generalized fractal dimension.

4. Results and discussion

We plot $\ln\langle F_q\rangle$ *vs* $-\ln d\phi$ in Figure 1 and the calculations were performed in azimuthal phase space and it was done for three different order of the moments. This allowed us to compare the consistency of power law behaviour among three different order of the moments. The best fits, satisfying the power law

$$\langle F_q\rangle \propto (\delta\,\phi/\Delta\phi)^{-\alpha_q},$$

where α_n are known as 'intermittency exponents,' are obtained and the values of α_q are found to be $0.178 \pm 0.036, 0.504 \pm 0.097, 0.810 \pm 0.078$ respectively.

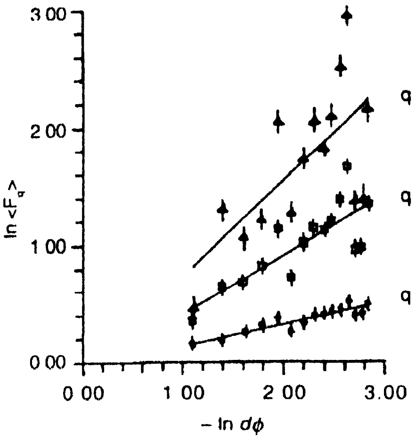

Figure 1. Variation of normalized SFM of orders 2, 3 and 4 with azimuthal angle (ln $<Fq>$ *vs* – ln $d\phi$) for muon-nucleus interactions at (420 ± 45) GeV

To minimize the errors in angle measurement, cross-checking by different observers was performed. Further, the analysis was restricted to M = 20, so that the minimum bin width for our analysis is always bigger than the maximum uncertainty in angle measurement in any direction in the emulsion. To cross-check our observation, we generate a random isotropic distribution with the same number of events and repeat our analysis, resulting

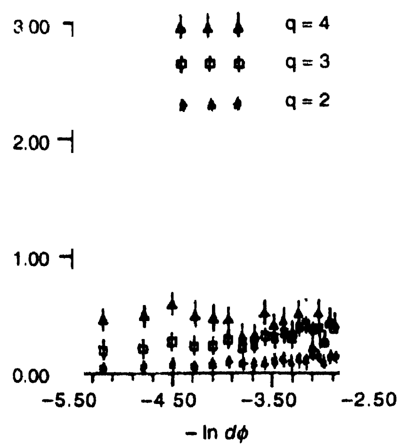

Figure 2. Variation of SFM of the same orders 2, 3 and 4 with azimuthal angle *i e.* (ln $<Fq>$ *vs* – ln $d\phi$) for random distribution in muon-nucleus interactions with same energy.

in Figure 2. A comparison of plots of ln <Fq> *vs* $-\ln d\phi$ in Figure 1 with that of Figure 2, thus confirms the presence of non-statistical intermittent type of fluctuation in the emission of black particles in ϕ space in muon-nucleus interactions at (420 ± 45) GeV.

Further, the generalized fractal dimensions Dq's are obtained from the slope values of α_q with the help of the relations (4) and (5) and are presented in Table 1. From Table 1, it is shown that the generalized fractal dimensions decrease with the increase of q-values which is a clear evidence of multifractality.

Table 1. Values of α_q and D_q for different q for black tracks of muon-nucleus interactions at (420 ± 45) GeV.

Values of q's	Values of α_q	Values of D_q
2	0 178 ± 0 036	0 82
3	0 504 ± 0 097	0 75
4	0 810 ± 0.078	0 72

5. Conclusions

Now, the most important point of this analysis is that one can get some idea about the state of affairs of disintegration mechanism of the target nucleus. The presence of intermittency has been observed in the angular distribution of black particles in azimuthal angle space. Therefore, it can be said that the experimentally observed emission of black particles during disintegration of target nucleus by muon is self-similar in nature. It further indicates that the concept of the statistical equilibrium of target nucleus during the emission of black particles, needs to be modified. Our present work also exhibits multifractality of target residues in muon-nucleus interactions initiated by muons at high energy.

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